AD-A092 472 NAVAL RESEARCH LAB WASHINGTON DC F/G 18/1
BEAM REQUIREMENTS FOR LIGHT-ION-DRIVEN INERTIAL-CONFINEMENT FUS--ETC(U)
NOV 80 D MOSHER, D G COLOMBANT, S A GOLDSTEIN
UNCLASSIFIED NRL-MR-4397 NL

1 OF 1
AD A
092472

END
DATE
FILMED
1-81
DTIC

AD A092472

(4) NRL-MR-4397

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 4397	2. GOVT ACCESSION NO. AD-A092472	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) BEAM REQUIREMENTS FOR LIGHT-ION-DRIVEN INERTIAL-CONFINEMENT FUSION.		5. TYPE OF REPORT & PERIOD COVERED (9) Final report. ~~on one part of~~ continuing NRL problem.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) D. Mosher, D. G. Colombant ~~and~~ Shyke A. Goldstein*		8. CONTRACT OR GRANT NUMBER(s) (12) 20
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, DC 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 67-0879-0-0
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Energy Washington, DC 20545	(11) 27	12. REPORT DATE November 1980
		13. NUMBER OF PAGES 21
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Sandia National Laboratories Albuquerque, NM 87115		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

*Present address: Jaycor, Inc., Alexandria, Va. 22304

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Light-ion-beams	System requirements
Ion focusing	Beam packing
~~Ion transport~~	Beam bunching
Inertial-confinement-fusion module	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Pulsed-power and ion-beam production and handling techniques are available to assemble a break-even ICF experiment. In this report, simple scaling laws for beam focusing, transport, bunching and packing are combined to define an acceptable range of parameters for ignition-system modules delivering low-atomic-number ($\leq$ 6) ion beams to a pellet. Techniques for increasing the deliverable beam intensity are then discussed.

Less than or equal to

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

i

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251150

A

BEAM REQUIREMENTS FOR LIGHT-ION-DRIVEN INERTIAL-CONFINEMENT FUSION

A

Proof-of-principal and scaling experiments for light-ion-driven inertial-confinement fusion are in progress with generators appropriate for use as ignition-system modules.[1,2] Megampere currents of 2 MeV protons and deuterons have recently been extracted in 100 ns pulses from 100 cm^2 pinch-reflex diodes (PRDs) operating at 3-TW diode electric powers.[3] Experiments at the 1-TW level have recorded focused proton-current densities approaching 1 MA/cm^2 with cylindrical magnetically-insulated diodes.[4] Deuterons extracted from PRDs have been focused to over 300 kA/cm^2 in a geometry appropriate for injection into transport channels.[3] Proton beams extracted from pinch-reflex diodes have been transported meter distances in the focused state through 50 kA wall-stabilized z-discharges established in 1 Torr gas backgrounds.[5] Experiments utilizing laser-initiated discharges are in progress.[6] Several-meter channel transport provides a means to deliver beams extracted from a large number of generators to the vicinity of the pellet. These lengths are sufficient to achieve beam power multiplication by axial bunching.[7] Computational MHD research[8] and microinstability calculations[9] indicate that individual proton beams with currents approaching 1 MA can be transported.

The cited work indicates that the pulsed-power and ion-beam production and handling techniques are available to assemble a break-even ICF experiment. In this comment, simple scaling laws for beam focusing, transport, bunching

Manuscript submitted October 6, 1980.

and packing are combined to define an acceptable range of parameters for ignition-system modules delivering low-atomic-number ($\lesssim 6$) ion beams to a pellet. Techniques for increasing the deliverable beam intensity are then discussed.

Figure 1 illustrates schematically one module for extraction, focusing and transport of an intense ion beam. Ions are accelerated axially across the diode vacuum gap by the applied electric field and are accelerated radially inward by their azimuthal self-magnetic field. The transmission cathode separates the diode region from a low-pressure, gas-filled drift section. Beam-induced breakdown of the gas reduces the self-magnetic field by about two orders of magnitude so that ion orbits in the drift section are nearly ballistic.[3] The anode and cathode structures are shaped so that ions exiting the diode converge to a focus at the entrance of the transport section. Beam ions are magnetically confined in the centimeter-diameter discharge channel and are transported to within a few centimeters of the pellet. The maximum injection angle of ions into the channel must be $\lesssim .2$ radian so that modest discharge currents ($\lesssim 50$ kA) suffice for beam confinement[2,7] and excessive expansion between the channel exit and pellet does not occur. For such injection and channel current conditions, ions of a few MeV/nucleon (which couple efficiently to the pellet[10]) can propagate in a range of channel-plasma densities limited from below by channel expansion during beam transit and from above by excessive collisional beam-energy loss.[8] Increasing the diode accelerating voltage during the ~ 50 ns injected ion pulse permits power multiplication during transport by axial bunching down to the ~ 10 ns required to drive the pellet.[10] Substantial power-multiplication can be achieved only when the dispersion in axial ion velocities during transport is small.[7] This condition is also satisfied by small ion-injection angles.

The accelerating-voltage waveform appropriate for beam bunching during transport produces ions which exit the diode with an axial velocity[2,7]

$$v_i(t) = \frac{v_i(0)}{1-t/T} \quad ; \qquad 0 \le t \le \tau < T \tag{1}$$

where τ is the ion pulse duration at the diode and T determines the voltage-ramp steepness. As the beam propagates in z, the beam duration is reduced according to

$$\Delta t = \tau\left[1 - \frac{z}{v_i(\tau)(T-\tau)}\right] \tag{2}$$

In order to reduce Δt to τ/α, propagation a distance

$$\ell = 1.3\times10^9(1-\alpha^{-1})(T-\tau)\sqrt{E/A} \quad \text{cm} \tag{3}$$

is required where E(MeV) is the ion energy at $t = \tau$ and A is the atomic weight and α is the power multiplication factor.

The accelerating-voltage ramp required for bunching produces a similarly-varying ion current. These time variations cause the magnetic pinch force in the diode to increase with time. In order to minimize defocusing with time at the entrance aperture of the transport section, the diode vacuum gap should decrease with time. With optimal gap-closure velocity,[11] residual time variations produce a focal-spot radius

$$r_s \simeq \frac{.15Z_D I}{\sqrt{AE}} \frac{(1-\tau/T)v\tau}{(R/F)} \quad \text{cm} \tag{4}$$

In Eq. (4), Z_D is the ion charge state in the diode, I(MA) is the ion current in the diode, v (cm/s) is the electrode-plasma velocity for cathode or anode, R is the diode radius and F is the focusing distance from diode to transport entrance aperture. The quantity R/F defines the maximum injection angle of ions into the focus.

The magnetic field produced by the channel current I_{ch}(MA) must confine these ions within the channel radius $r_{ch} > r_s$. From conservation of canonical momentum[2,7]

$$I_{ch} \gtrsim 1.3 \frac{\sqrt{AE}}{Z_T} (R/F)^2 \tag{5}$$

where $r_s^2 = r_{ch}^2/2$ has been assumed, and Z_T is the beam charge state in the discharge. Collisions with discharge-plasma electrons can produce a charge state different from that in diode.[12] The transporting beam current $I_T = (Z_T/Z_D)I$ produces a plasma-return current of nearly-equal magnitude. The channel expands under the influence of the resulting $j_z B_\theta$ force. MHD calculations demonstrate acceptable channel expansion when[2,8]

$$I_T I_{ch} \lesssim 3\times10^{-10} \frac{\rho r_{ch}^4}{\tau^2} \tag{6}$$

where ρ(g/cm^3) is the channel-plasma mass density.

The channel-response calculations[8] determine the $V_r B_\theta$ electric field which removes energy from the beam as well as collisional energy losses. Minimum beam energy loss occurs at the plasma density where these two loss rates are equal since the former is proportional to ρ while the latter is proportional to ρ^{-1}. For a fully-ionized deuterium plasma,[13] this optimum density is given by

$$\rho_{opt} = \frac{.12 I_{ch}}{r_{ch}^2} \sqrt{\frac{IE\tau}{AZ_D}} \tag{7}$$

and the corresponding total beam-energy loss rate in the channel is

$$\frac{dE}{dz} \approx \frac{2\times10^3 A Z_T^2 \rho_{opt}}{E} \quad \text{MeV/cm} . \tag{8}$$

Substituting the optimum density into Eq. (6) leads to

$$\frac{Z_T \tau^{3/2}}{r_{ch}^2} \sqrt{\frac{AI}{Z_D E}} \leq 3.5\times10^{-11} \quad . \tag{9}$$

An estimate of the minimum total energy loss experienced during transport is

$$\Delta E = \ell \frac{dE}{dz} \quad . \tag{10}$$

Requiring that ΔE be no more than a quarter of E leads to the condition

$$\frac{Z_T \tau^{3/2}}{r_{ch}^2} \sqrt{\frac{AI}{Z_D E}} \leq \frac{7\times10^{-13}}{(1-\alpha^{-1})(T/\tau-1)(R/F)^2} \quad . \tag{11}$$

A larger energy loss at $t=\tau$ is unacceptable because lower-energy ions emitted earlier already experience greater losses.

Equation (9) must be satisfied when $(R/F) \leq (R/F)_c$ while Eq. (11) must be satisfied otherwise where

$$(R/F)_c^2 = \frac{.02}{(1-\alpha^{-1})(T/\tau-1)} \quad . \tag{12}$$

For the purpose of discussion, the above relations can be simplified by assuming that $Z_D = Z_T = Z$. Also, the beam-energy can be eliminated by adjusting E with species to maintain a constant deposition length in the target.[14] Since the stopping power scales roughly like AZ^2/E, constant range results when

$$E^2 = AZ^2E_0^2 \quad . \tag{13}$$

In Eq. (13), E_0 is the proton energy of equivalent range. With this energy scaling, a particularly simple form results when Eqs. (9) and (11) are written in terms of beam power $P(TW) = IE/Z$.

$$P \le \frac{1.2\times10^{-21}E_0^2 r_{ch}^4}{\tau^3} \begin{cases} 1 & (R/F) \le (R/F)_c \\ \dfrac{(R/F)_c^4}{(R/F)^4} & (R/F) > (R/F)_c \end{cases} \qquad (14)$$

It is noteworthy that Eq. (14) is species independent. Note also that P refers to the power extracted from the diode. As the beam bunches, $P\tau$ remains constant so that Eq. (14) becomes easier to satisfy.

Applying the considerations of the previous paragraph to Eq. (4) with $r_s \le r_{ch}/\sqrt{2}$ leads to

$$P \le \frac{4.6E_0^{3/2}A^{5/4}}{Z^{\frac{1}{2}}} \frac{(R/F)r_{ch}}{(1-\tau/T)v\tau} \qquad (15)$$

Equations (14) and (15) are plotted in Fig. 2 for E_0 = 2 MeV, r_{ch} = .5 cm, τ = 50 ns, v = 1×10^7 cm/s, α = 5 and τ/T = .2. The velocity is consistent with observed electrode-plasma expansion.[15] The τ/T value corresponds to a voltage which rises 50% during the pulse. These results suggest that limits to focusability constrain deliverable modular beam power for protons while lack of beam confinement and energy loss during transport limit beam power for heavier ions. In either case, very long focal lengths (R/F ≤ .1) are required for transport of maximum beam power. Since focusability may be limited by a number of factors not considered here (electrode-plasma instabilities, asymmetric diode fields, beam-plasma interaction in the focusing drift region or effects peculiar to advanced focusing diode designs not yet discovered), operation at the largest R/F values possible would be desirable. However, increasing R/F increases beam expansion between the channel exit and pellet. Therefore, beam overlap on target must be considered to determine optimum power and injection angle regimes of operation.

For channel exits located a distance d from the pellet, each beam expands to a radius r_{ch} + d(R/F) before impacting on target. The average power density on target can then be approximated by

$$p = \frac{NP\alpha}{4\pi\left[r_{ch}+d(R/F)\right]^2} \tag{16}$$

where N is the total number of transported beams. Assuming that no more than 25% of 4π steradians is subtended by the channel-exit aperture area, the maximum number of beams is given by $(d/r_{ch})^2$. The power density on target therefore satisfies

$$p \leq \frac{NP\alpha}{4\pi r_{ch}^2\left[1+N^{\frac{1}{2}}(R/F)\right]^2} \quad . \tag{17}$$

Since the pellet design specifies p and the facility configuration determines N, Eq. (17) represents an additional constraint which P must satisfy. This constraint is plotted in Fig. (3) for N = 36 and 72 modules and two values of p. Other parameters are as in Fig. 2. The lower p value corresponds to the incident power density required to drive a 1 cm diameter break-even pellet of recent design.[16] Acceptable operating ranges are defined by the regions above these curves and below the expansion/energy-loss curve. Thus, operation appears to be limited to the below .1 radian regime unless techniques can be employed to relieve the expansion/energy-loss constraints. Various options to achieve this are now considered.

Slight increases in $(R/F)_c$ are achieved when the voltage-ramp steepness is increased. This may not be beneficial since low energy ions emitted at early times suffer strong energy losses during transport.[8] Low energy ions do not penetrate deeply enough into the pellet to efficiently couple energy

to the fuel. Thus, propagation of several-TW beams at R/F values in excess of .1 may require substantial increases in $E_0^2 r_{ch}^4/\tau^3$. A 2 TW beam could be propagated at R/F = .15 by increasing E_0 to 3 MeV, decreasing τ to 40 ns and increasing r_{ch} to .6 cm. The increase in E_0 requires pellets designed for longer deposition lengths. The Sandia National Laboratories PBFA facility is designed with $\tau \leq 40$ ns so that the decrease in τ presents no difficulty. The channel radius can be increased provided a final-focusing stage can be added at the channel exit.[7,17] Limitations to deliverable beam power can also be relaxed by employing a discharge channel which is imploding rather than static at the time of beam injection.[18] The MHD expansion constraint is relaxed since an imploding channel must experience stronger radial acceleration for a longer time before reaching an expanded state. Such dynamic channels have imbedded electric fields which tend to accelerate the beam,[18] thus reducing energy loss as well.

Scale-up of $E_0^2 r_{ch}^4/\tau^3$, dynamic channels or a combination of both techniques can be used to extend allowable R/F values or increase beam power in the transport section. For low pellet irradiance, these techniques may permit delivery of few TW beams with R/F values as large as .15. Proton-beam focusability precludes their use in high-irradiance configurations. When the same focusing constraint is applied to higher-atomic-number beams, high-irradiance operation with a standard, static channel is permitted with R/F ≈ .05. For reasons discussed in the paragraph following Eq. (15), focusing with such small R/F values is, at best, uncertain. Thus, application of advanced techniques to transport of non-hydrogenic beams is desirable in order to permit high pellet irradiance at R/F ≈ .1.

REFERENCES

1. G. W. Kuswa and T. H. Martin, Proc. Topical Mtg. on Inertial Confinement Fusion, Feb. 26-28, 1980, San Diego, p. 82.

2. D. Mosher, G. Cooperstein, S. A. Goldstein, D. G. Colombant, P. F. Ottinger, F. L. Sandel, S. J. Stephanakis and F. C. Young, Proc. Third International Conf. on High Power Electron and Ion Beam Research and Technology, July 3-6, 1979, Novosibirsk, p. 576.

3. G. Cooperstein, Shyke A. Goldstein, D. Mosher, R. J. Barker, J. R. Boller, D. G. Colombant, A. Drobot, R. A. Meger, W. F. Oliphant, P. F. Ottinger, F. L. Sandel, S. J. Stephanakis, and F. C. Young, Proc. Fifth Workshop on Laser Interaction and Related Plasma Phenomena, Nov. 5-9, 1979, Rochester.

4. D. J. Johnson, G. W. Kuswa, A. V. Farnsworth, Jr., J. P. Quintenz, R. J. Leeper, E. J. T. Burns, and S. Humphries, Jr., Phys. Rev. Lett. 42, 610 (1979); D. J. Johnson, Bull. Am. Phys. Soc. 24, 925 (1979).

5. F. L. Sandel, F. C. Young, S. J. Stephanakis, W. F. Oliphant, G. Cooperstein, S. A. Goldstein and D. Mosher, Bull. Am. Phys. Soc. 24, 1031 (1979).

6. J. N. Olsen, D. J. Johnson and L. Baker, Bull. Am. Phys. Soc. 24, 978 (1979).

7. P. F. Ottinger, D. Mosher and Shyke A. Goldstein, Phys. Fluids 23, 909 (1980).

8. D. G. Colombant, D. Mosher and Shyke A. Goldstein, NRL Memorandum Report 4252 (1980). To be published.

9. P. F. Ottinger, D. Mosher and Shyke A. Goldstein, Phys. Fluids 22, 332 (1980). Also NRL Memorandum Rep. 4088, 1980.

10. S. Jorna and N. Metzler, Proc. IEEE International Conf. on Plasma Sci., May 19-21, 1980, Madison, p. 37.

11. D. Mosher, G. Cooperstein and Shyke A. Goldstein, Proc. Topical Mtg. on Inertial Confinement Fusion, Feb. 26-28, 1980, San Diego, p. 104.

12. T. A. Mehlhorn, Sandia National Lab. Rep. SAND80-0038, 1980.

13. Deuterium plasma has the advantage over hydrogen of 1/2 the stopping power.

14. P. A. Miller, informal communication.

15. R. D. Genuario, J. Maenchen, R. Stringfield, G. Cooperstein, D. Mosher, S. J. Stephanakis and S. A. Goldstein, Proc. IEEE International Conf. on Plasma Science, May 19-21, 1980, Madison, p. 13.

16. G. O. Allshouse, informal communication.

17. P. F. Ottinger, Shyke A. Goldstein and D. Mosher, Proc. IEEE International Conf. on Plasma Science, May 19-21, 1980, Madison, p. 95.

18. Shyke A. Goldstein and D. A. Tidman, Proc. IEEE International Conf. on Plasma Science, May 19-21, 1980, Madison, p. 96.

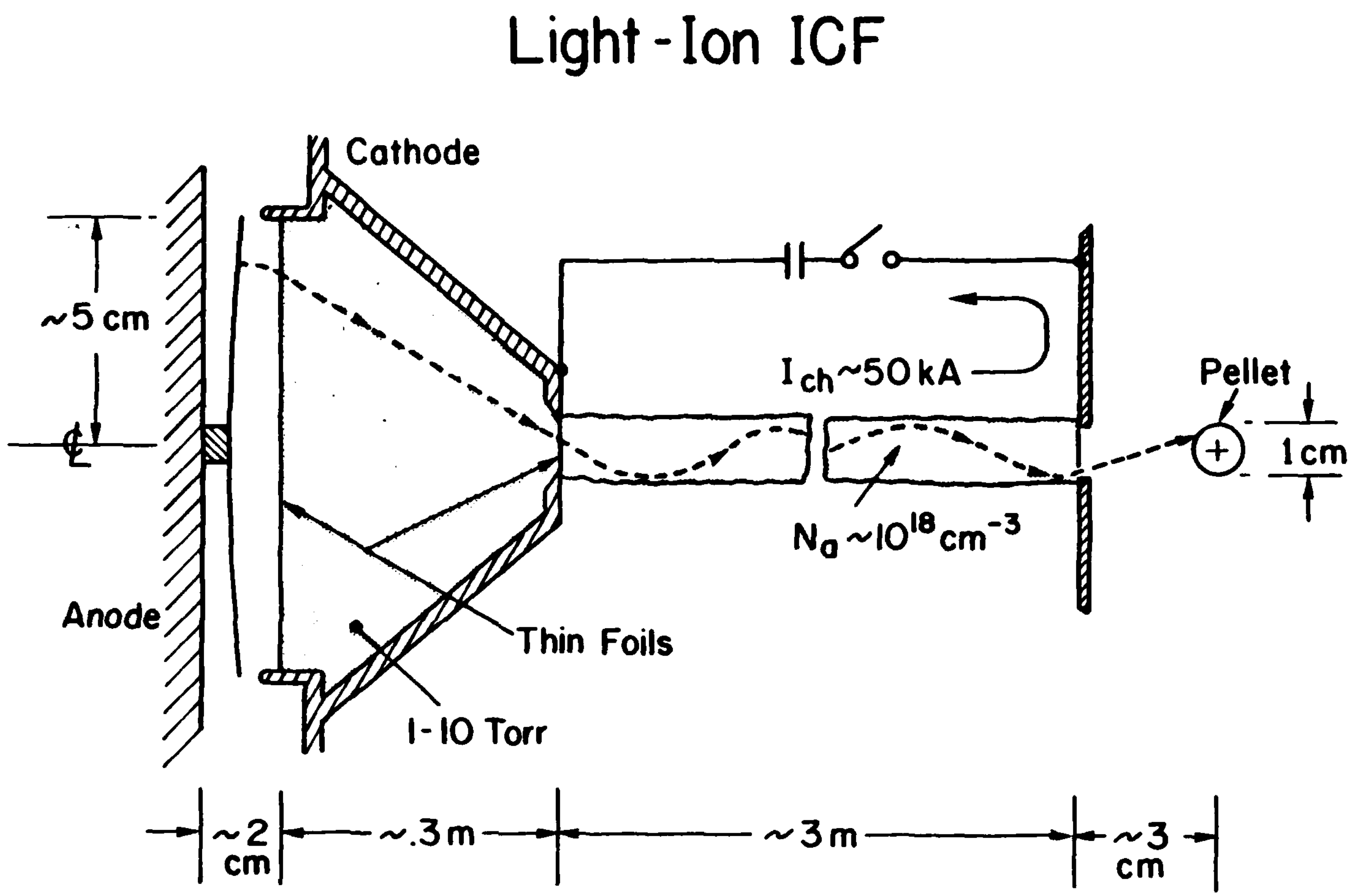

Fig. 1 — Conceptual schematic of one light-ion ICF module showing a pinch-reflex diode, focusing-drift region, and transport channel

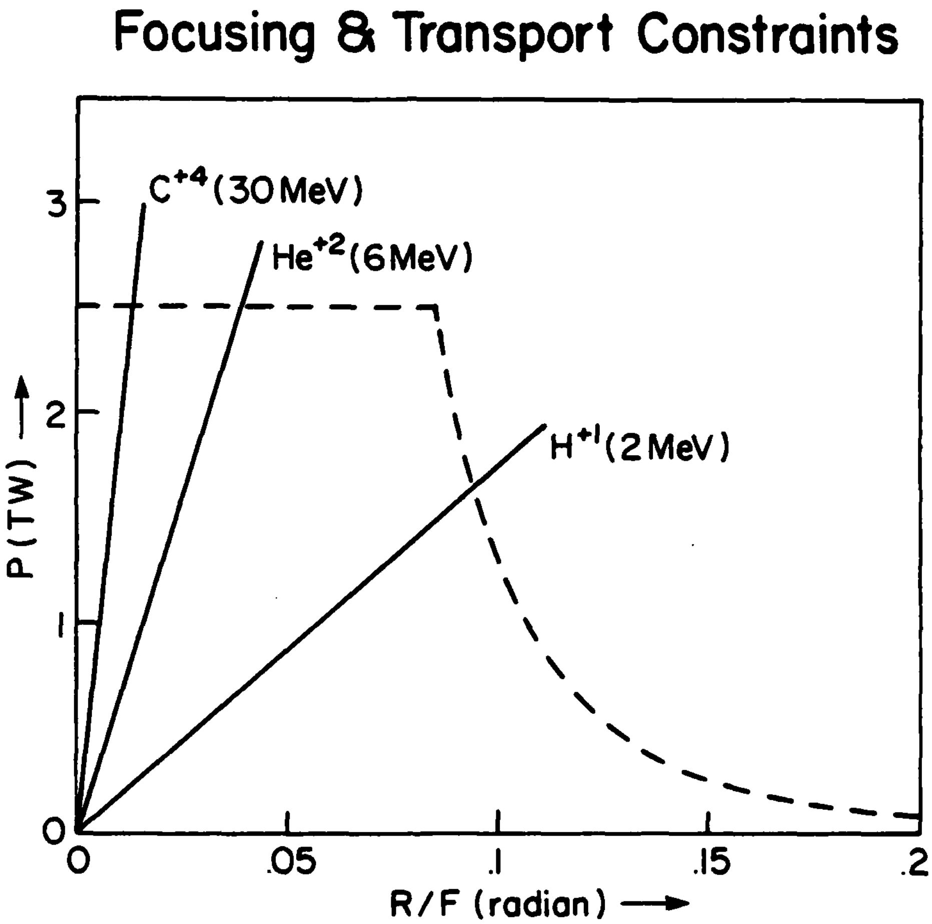

Fig. 2 — Beam power constraints as a function of the maximum injection angle of ions into the channel. The solid lines represent the maximum focusable power for the species and energies shown. The dashed line represents the maximum transportable power for all species.

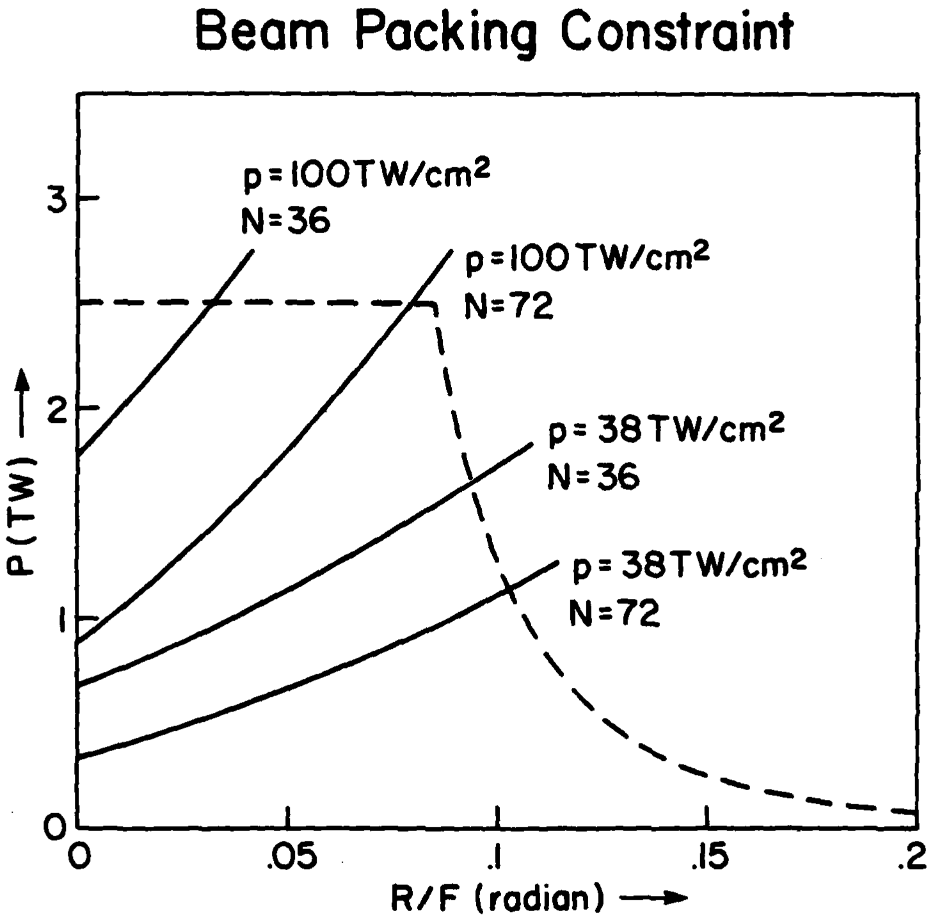

Fig. 3 — Beam packing constraints for two pellet-irradiance requirements and two ion-module-number values. Acceptable operation is associated with beam powers above the curves but subject to the maximum power displayed in Fig. 2.

DISTRIBUTION LIST

Director
Defense Intelligence Agency
Washington, DC 20301

Attn: DTICI Robert I. Rubenstein — 1 copy

Defense Advanced Research Project Agency
1400 Wilson Blvd.
Arlington, VA 22209
Attn: R. Bayless — 1 copy

Director
Defense Nuclear Agency
Washington, DC 20305

Attn:
- FCPR — 1 copy
- STVL — 1 copy
- TISI Archives — 1 copy
- TITL Tech. Library — 3 copies
- J. Z. Farber (RAEV) — 1 copy
- R. L. Gullickson (RAEV) — 1 copy

Defense Technical Information Center
Cameron Station
5010 Duke Street
Alexandria, VA 22314

Attn: T. C. — 12 copies

Under Sec'y of Defense for RSCH and ENGRG
Department of Defense
Washington, DC 20301

Attn: S&SS(OS) — 1 copy

Chief
Livermore Division Fld Command DNA
Lawrence National Laboratory
P. O. Box 808
Livermore, CA 94550

Attn: FCPRL — 1 copy

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161 — 24 copies

Commander
BMD System Command
P. O. Box 1500
Huntsville, AL 35807

Attn: SSC-TEN — 1 copy

DEP Chief of Staff for RSCH DEV & ACQ
Department of the Army
Washington, DC 20310

Attn: DAMA-CSM-N — 1 copy

Commander
Harry Diamond Laboratories
2800 Powder Mill Road
Adelphi, MD 20783
(CNWDI-INNER ENVELOPE: ATTN: DELHD-RBH)

Attn:
- DELHD-NP — 1 copy
- DELHD-RCC J. A. Rosado — 1 copy
- DRXDO-RBH P. A. Caldwell — 1 copy
- DRXDO-RBH D. Schallhorn — 1 copy
- DRXDO-TI Tech Lib. — 1 copy
- S. Graybill — 1 copy

Commander
Picatinny Arsenal
Dover, NJ 07801

Attn: SMUPA ND-N-E — 1 copy

Commander
U. S. Army Missile Command
Redstone Arsenal, AK 35809

Attn: Redstone Scientific Information CTR
DRCPM-PM-PE-EA — 1 copy

Commander
U. S. Army Nuclear Agency
7500 Backlick Road
Building 2073
Springfield, VA 22150

Attn: ATCN-W — 1 copy

Commander
U. S. Army Test and Evaluation COMD
Aberdeen Proving Ground, MD 21005

Attn: DRSTE-EL — 1 copy

Commander
Naval Electronic Systems CMD HQS
Washington, DC 20360

Attn: Code 5032 — 1 copy

Commanding Officer
Naval Intelligence Support Center
4301 Suitland Road - Building 5
Washington, DC 20390

Attn: NISC-45 — 1 copy

Naval Research Laboratory
Addressee: Attn: Name/Code

Code 2628 - TIC-Distribution	25 copies
Code 4020 - J. Boris	1 copy
Code 6682 - D. Nagel	1 copy
Code 4700 - T. Coffey	25 copies
Code 4707 - J. Davis	1 copy
Code 4730 - S. Bodner	1 copy
Code 4740 - V. Granatstein	1 copy
Code 4760 - B. Robson	1 copy
Code 4761 - C. Kapetanakos	1 copy
Code 4770 - Branch Head	10 copies
Code 4770.1 I. Vitkovitsky	1 copy
Code 4771 - D. Mosher	10 copies
Code 4773 - G. Cooperstein	10 copies
Code 4790 - D. Colombant	1 copy
Code 4790 - I. Haber	1 copy
Code 4790 - M. Lampe	1 copy

Officer-in-Charge
Naval Surface Weapons Center
White Oak, Silver Spring, MD 20910

Attn: Code WR43 — 1 copy
Code WA501 - Navy Nuc Prgms Off — 1 copy

Chief of Naval Operations
Navy Department
Washington, DC 20350

Attn: R. A. Blaise 604C4 — 1 copy

Commander
Naval Weapons Center
China Lake, CA 93555

Attn: Code 533 Tech Lib. — 1 copy

AF Weapons Laboratory, AFSC
Kirtland AFB, NM 87117

Attn: CA	1 copy
ELC	1 copy
NT	1 copy
SUL	1 copy
DYP	1 copy
J. Darrah	1 copy
W.L. Baker	1 copy

HQ USAF/RD
Washington, DC 20330

Attn: RDQSM — 1 copy

Director
Joint Strat TGT Planning Staff JCS
OFFUTT AFB
Omaha, NB 68113

Attn: JSAS — 1 copy

SAMSO/DY
Post Office Box 92960
Worldway Postal Center
Los Angeles, CA 90009
(Technology)

Attn: DYS — 1 copy

SAMSO/IN
Post Office Box 92960
Worldway Postal Center
Los Angeles, CA 90009

Attn: IND MAJ D. S. Muskin — 1 copy

SAMSO/MN
Norton AFB, CA 92409
(Minuteman)

Attn: MNNH — 1 copy

SAMSO/SK
Post Office Box 92960
Worldway Postal Center
Los Angeles, CA 90009
(Space Comm Systems)

Attn: SKF P. H. Stadler — 1 copy

U. S. Department of Energy
Division of Inertial Fusion
Washington, DC 20545

Attn: G. Canavan	2 copies
T. F. Godlove	1 copy
S. L. Kahalas	1 copy

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

Attn: G. R. Magelssen	1 copy
R. J. Martin	1 copy

Brookhaven National Laboratory
Upton, NY 11973

Attn: A. F. Maschke — 1 copy

Lawrence Berkley Laboratory
Berkeley, CA 94720

Attn: D. Keefe — 1 copy

Lawrence Livermore National Laboratory
P. O. Box 808
Livermore, CA 94550

Attn: L-18	1 copy
L-153	1 copy
R. O. Bangerter	1 copy
R. J. Briggs	1 copy
E. P. Lee	1 copy
J. H. Nuckolls	1 copy
S. S. Yu	1 copy
Tech Info Dept. L-3	1 copy

Los Alamos National Laboratory
P. O. Box 1663
Los Alamos, NM 87545

Attn: D. B. Henderson	1 copy
R. B. Perkins	1 copy
L. E. Thode	1 copy

National Bureau of Standards
Washington, DC 20234

Attn: J. Leiss 1 copy

National Science Foundation
Mail Stop 19
Washington, DC 20550

Attn: D. Berley 1 copy

Sandia National Laboratories
P. O. Box 5800
Albuquerque, NM 87115

Attn: J. R. Freeman	1 copy
S. Humphries	1 copy
D. J. Johnson	1 copy
G. W. Kuswa	1 copy
P. S. Miller	1 copy
J. P. Vandevender	1 copy
G. Yonas	1 copy
Doc Con for 3141 Sandia RPT Coll	1 copy

AVCO Research and Systems Group
201 Lowell Street
Wilmington, MA 01887

Attn: Research Lib. A830 Rm. 7201 1 copy

BDM Corporation, The
795 Jones Branch Drive
McLean, VA 22101

Attn: Tech Lib. 1 copy

Boeing Company, The
P. O. Box 3707
Seattle, WA 98124

Attn: Aerospace Library 1 copy

Cornell University
Ithaca, NY 14850

Attn: D. A. Hammer	1 copy
R. N. Sudan	1 copy
J. Maenchen	1 copy

Dikewood Industries, Inc.
1009 Bradbury Drive, SE
Albuquerque, NM 87106

Attn: L. W. Davis 1 copy

EG&G, Inc.
Albuquerque Division
P. O. Box 10218
Albuquerque, NM 87114

Attn: Technical Library 1 copy

Ford Aerospace & Communications Operations
Ford & Jamboree Roads
Newport Beach, CA 92663
(Formerly Aeronutronic Ford Corporation)

Attn: Tech Info Section 1 copy

Ford Aerospace & Communications Corp
3939 Fabian Way
Palo Alto, CA 94303
(Formerly Aeronutronic Ford Corporation)

Attn: Library	1 copy
D. R. McMorrow MS G 30	1 copy

General Electric Company
Space Division
Valley Forge Space Center
Goddard Blvd., King of Prussia
P. O. Box 8555
Philadelphia, PA 19101

Attn: J. C. Penden VFSC, Rm. 4230M 1 copy

General Electric Company
Tempo-Center for Advanced Studies
816 State Street (P. O. Drawer QQ)
Santa Barbara, CA 93102

Attn: DASIAC 1 copy

Grumman Aerospace Corporation
Bethpage, NY 11714

Attn: P. Suh 1 copy

Institute for Defense Analyses
400 Army-Navy Drive
Arlington, VA 22202

Attn: IDA Librarian R S. Smith 1 copy

Ion Physics Corporation
South Beford Street
Burlington, MA 01803

Attn: H. Milde — 1 copy

Ian Smith Associates
3115 Gibbens Dr.
Alameda, CA 94501
Attn: I. Smith — 2 copies

IRT Corporation
P. O. Box 81087
San Diego, CA 92138

Attn: R. L. Mertz — 1 copy

JAYCOR, Inc.
205 S. Whiting Street
Alexandria, VA 22304

Attn: J. Guillory — 1 copy
R. Hubbard — 1 copy
R. Sullivan — 1 copy
D. A. Tidman — 1 copy

JAYCOR, Inc.
1401 Camino Del Mar
Del Mar, CA 97014

Attn: E. Wenaas — 1 copy

JAYCOR, Inc.
300 Unicorn Park Drive
Woburn, MA 01801

Attn: H. Linnerud — 1 copy

Kaman Science Corporation
P. O. Box 7463
Colorado Springs, CO 80933

Attn: A. P. Bridges — 1 copy
D. H. Bryce — 1 copy
J. R. Hoffman — 1 copy
W. E. Ware — 1 copy

Lockheed Missiles and Space Co., Inc.
3251 Hanover Street
Palo Alto, CA 94304

Attn: L. F. Chase — 1 copy

MIT
Massachusetts Institute of Technology
Cambridge, MA. 02139

Attn: R.C. Davidson — 1 copy
G. Bekefi — 1 copy
D. Hinshelwood — 1 copy

Maxwell Laboratories, Inc.
9244 Balboa Avenue
San Diego, CA 92123

Attn: R. W. Clark — 1 copy
A. C. Kolb — 1 copy
P. Korn — 1 copy
A. R. Miller — 1 copy
J. Pearlman — 1 copy

McDonnell Douglas Corporation
5301 Bolsa Avenue
Huntington Beach, CA 92647

Attn: S. Schneider — 1 copy

Mission Research Corporation
1400 San Mateo Blvd. SE
Albuquerque, NM 87108

Attn: B. B. Godfrey — 1 copy

Mission Research Corporation-San Diego
P. O. Box 1209
LaJolla, CA 92038

Attn: V.A.J. Van Lint — 1 copy

Mission Research Corporation
735 State Street
Santa Barbara, CA 93101

Attn: W. C. Hart — 1 copy
C. L. Longmire — 1 copy

Northrop Corporation
Electronic Division
2301 West 120th Street
Hawthorne, CA 90250

Attn: V. R. DeMartino — 1 copy

Northrop Corporation
Northrop Research and Technology Ctr.
3401 West Broadway
Hawthorne, CA 90205 — 1 copy

Physics International Co.
2700 Merced Street
San Leandro, CA 94577

Attn: J. Benford — 1 copy
B. Bernstein — 1 copy
R. Genuario — 1 copy
E. B. Goldman — 1 copy
A. J. Toepfer — 1 copy

Pulsar Associates, Inc.
11491 Sorrento Valley Blvd.
San Deigo, CA 92121

Attn: C. H. Jones, Jr. — 1 copy

R&D Associates
P. O. Box 9695
Marina Del Rey, CA 90291

Attn: W. R. Graham, Jr. 1 copy
M. Grover 1 copy
C. MacDonald 1 copy
E. Martinelli 1 copy
L. Schlessinger 1 copy

Science Applications, Inc.
P. O. Box 2351
LaJolla, CA 92038

Attn: J. Robert Beyster 1 copy

Spire Corporation
P. O. Box D
Bedford, MA 01730

Attn: R. G. Little 1 copy

SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Attn: Setsuo Odairiki 1 copy

Stanford University
SLAC
P. O. Box 4349
Stanford, CA 94305

Attn: W. B. Herrmannsfeldt 1 copy

Systems, Science and Software, Inc.
P. O. Box 4803
Hayward, CA 94540

Attn: D. A. Meskan 1 copy

Systems, Science and Software, Inc.
P. O. Box 1620
LaJolla, CA 92038

Attn: A. R. Wilson 1 copy

Texas Tech University
P. O. Box 5404 North College Station
Lubbock, TX 79417

Attn: T. L. Simpson 1 copy

TRW Defense and Space Sys Group
One Space Park
Redondo Beach, CA 90278

Attn: Tech Info Center/S-1930 1 copy

University of California
Dept. of Physics
La Jolla, CA 92037

Attn: K. Brueckner 1 copy

University of California
Boelter Hall 7731
Los Angeles, CA 90024

Attn: F.F. Chen 1 copy

University of California
Irvine, CA 90024

Attn: G. Benford 1 copy
N. Rostoker 1 copy

University of Illinois
Urbana, IL 61801

Attn: G. H. Miley 1 copy
J. T. Verdeyen 1 copy

University of Rochester
Laboratory of Laser Energetics
River Station, Hopeman 110
Rochester, NY 14627

Attn: M. J. Lubin 1 copy

U. S. Department of Energy
P. O. Box 62
Oak Ridge, TN 37830 50 copies

Vought Corporation
Michigan Division
38111 Van Dyke Road
Sterling Heights, MI 48077
(Formerly LTV Aerospace Corp)

Attn: Tech Lib 1 copy

Bhabha Atomic Research Centre
Bombay - 400085, India

Attn: B. K. Godwal 1 copy

CEA, Centre de Etudes de Lemeil
B. P. 27
94190 Villeneuve, Saint George
France

Attn: A. Bernard 1 copy
A. Jolas 1 copy

CEA, Centre de Etudes de Valduc
P. B. 14
21120 Is-sur-Tille
France

Attn: J. Barbaro 1 copy
C. Bruno 1 copy
N. Camarcat 1 copy
C. Patou 1 copy
C. Peugnet 1 copy

Centro Di Frascati
C.P.N. 65
00044 Frascati (Roma)
Italy

Attn: J.P. Rajer 1 copy

Ecole Polytechnique
Labo. PMI
91128 Palaseau Cedex
France

Attn: J. M. Buzzi 1 copy
H. Doucet 1 copy

Institut d'Electronique Fondamentale
Universite' Paris XI-Bat. 220
F91405 Orsay
France

Attn: G. Gautherin 1 copy

Institut Fur Neutronenphysik
un Reaktortechnik
Postfach 3640
Kernforschungszentrum
D-7500 Karlsruhe 1
West Germany

Attn: H. U. Karow 1 copy
W. Schmidt 1 copy

Institute of Atomic Energy
Academia Sinica - Peking
People's Republic of China

Attn: R. Hong 1 copy

Institute of Laser Engineering
Osaka University
Yamadakami
Suita
Osaka 565, Japan

Attn: K. Imasaki 1 copy
S. Nakai 1 copy

Instituto De Investigaciones Cientificas Y Technicas
De Las Fuerzas Armadas
Aufriategui y Varela
V. Martelli 1603
Pcia Bs. As. - R. Argentina

Attn: N. B. Camusso 1 copy

Max-Planck-Institut fur Plasmaphysik
8046 Garching bei Munchen
West Germany

Attn: R. Lengyel 1 copy

Physical Research Laboratory
Navrangpura
Ahmedabad - 380009 - India

Attn: V. Ramani 1 copy

Shivaji University
Kolhapur, India

Attn: L. N. Katkan 1 copy

Weizmann Institute of Science
Rehovot, Israel

Attn: A. E. Blaugrund 1 copy
E. Nardi 1 copy
Z. Zinamon 1 copy